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# Smart Materials: The Next Generation

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## Introduction

Smart materials (SMs) are substances that exhibit systematic behavioral changes in response to a given stimulus, according to Rögen (1989). Changes in chemical or magnetic fields, or both, as well as changes in stress, sound, temperature, or radioactive radiation, are all examples of possible stimuli (Fig. 1). There are five ways in which these materials stand out from the crowd: they are direct, immediate, selected, and direct. independent action and fleeting nature (Addington and Schoedeck, 2006).

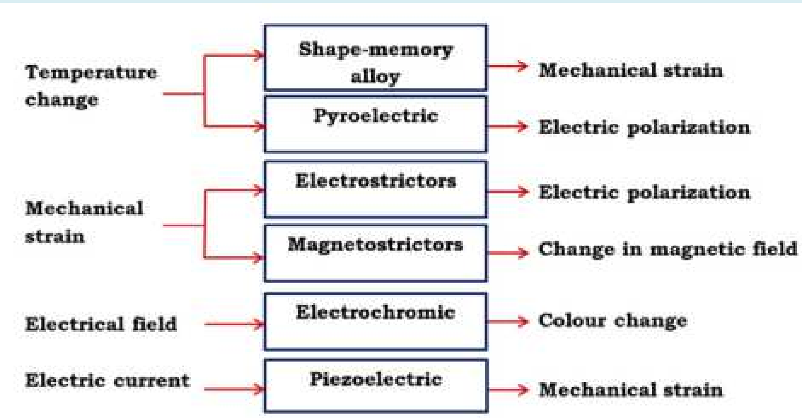


**Fig 1 Effect of external stimulus on some SMs.**

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More and more often, SMs are being designed and manufactured. Particularly in technological and medical contexts, they provide substantial benefits. Research from throughout the world indicates that smart materials will be worth $73.9 billion by 2023, having grown at a rate of 13% annually. The SM next generation emerged as a result of all these factors. In most cases, composites consisting of two or more constituents constitute the subsequent generation of such materials. The primary motivation for this is to decrease the active ingredient's cost, weight, and duration.

The goal of this piece is to lay out the future of SMs in various contexts. The composition, characteristics, and synthesis mechanism of the supermassive black hole production that follows is covered in this article. Research on other smart buildings that could have electrical, medicinal, and construction applications is also mentioned in the article.

### The Next Generation: Materials Classifications, Mechanisms and Characteristics

In the sections that follow, we will talk about the smart materials of the future (Maurya et al., 2020; Saye, 2020):

### Active Smart Materials (ASMs)

For instance, if the material undergoes a change in its geometrical or material qualities, it is referred to as ASM.

### Shape-memory materials

When NASA first started looking into shape memory polymers, it was with the intention of making flights safer. These materials retain their form when subjected to changes in temperature or pressure. Due to the shape memory effect, they return to their initial form as soon as the stimulus is removed. The three primary categories of shape memory materials are manner influence, two-manner influence, and pseudo-elasticity impact. The use of shape memory polymers is widespread across many different areas, including healthcare, aviation, and renewable energy. Shape memory polymers used by the aerospace sector were studied by WM Huang et al. Despite the cheap cost of Cu and Fe based SMAs, they said that ferrous polycrystalline SMs alloys exhibited exceptional flexibility and excellent tensile strength. Luang et al. (2010) states that certain SMAs have a temperature memory effect, allowing for regulated bending in response to changes in temperature.

Nitinol (NITI) is the strongest alloy in this area. It has the potential to regain its original form throughout a broad temperature range (-200 to 100°C). According to Maurya et al. (2020), the nickel-to-titanium ratio dictates the temperature range in which alloys are formed. Its exceptional flexibility, corrosion resistance, and fatigue resistance lend credence to its use in the aviation sector (Lobo et al., 2015). Actuators employ NM strips to increase engine efficiency and decrease cooling system requirements (Suman et al., 2015).

The development of shape-memory polymers (SMPS) allowed for the storage of motion energy. A triboelectric nanogenerator (TNG) using organic materials in their thermally induced state forms the backbone of the suggested method (Liu et al., 2018). A total of 150 light-emitting LEDs were effectively turned on by hand tapping. Nevertheless, these materials are ideal for wearable technology due to their flexibility and durability. Shape memory polymers based on trimethyl glycine (TNG) have the potential to sense and store biomechanical energy. Compared to other shape memory materials, they aren't as strong and don't transfer heat well. Aircraft use them because they can withstand long-term deformations and aerodynamic pressure (Yazik and Sultan, 2015). The characteristics of SMP could be enhanced by adding certain additives. For instance, according to Rama and Karger-Kocsis (2008), the molecular weight and recovery temperature of biodegradable polyglycolide may be changed.

One advantage of shape memory composites over polymer matrix composites (PMC) is its ability to withstand very high temperatures. The structural robustness, extreme rigidity, and low mass ratio of aluminum oxide composites are all impressive. The ceramic components of matrix composites contribute to their excellent combustion efficiency. As per Choubey et al. (2018), Sinart composites are also used in orbit to track trash and how it affects satellites.

**Magnetostrictive materials**

A material is considered magnetostrictive if it undergoes rapid variations in magnetic field strength. Terfenol-D alloy, which contains terbium, iron, and dysprosium, has shown the largest magnetic tostrictive action of any material known to date, surpassing 2000 μ. Level detectors are the most common applications of magnetostrictive materials. A vital component of the working mechanism is the presence of SMs, which are essentially a wire encircled by electrical pulses generated by an attached electronic device, resulting in a magnetic field. Attached to a float floating on the surface of the liquid is a magnet. The probe's meeting with the magnetic field causes the wire to twist in response to variations in the liquid level. Next, take an accurate reading of the liquid level.

**Bicomponent fibers**

Various structural arrangements may accomplish the desired effects when two materials with the same precursor but distinct mechanical, chemical, and physical characteristics are used. Three types are present in this field:

Two materials are said to be side-by-side if they are able to adhere to each other and provide mechanical support for their bond. Materials like self-crimping fibers made of a copolymer mix of polypropylene and ethylene octene will find usage in the texturing industry.

Materials having a core that is encased by a sheath are used in this design. The textile sector may likewise benefit from this SM design if it is used well. The engineer may, for instance, combine a high-strength fiber core with a supple covering.

Because it incorporates the transformation of one material into another, matrix-fibril is the most intricate SM design. Artificial veins made of very fine fibers employ it to achieve a density of 1.11e-05.

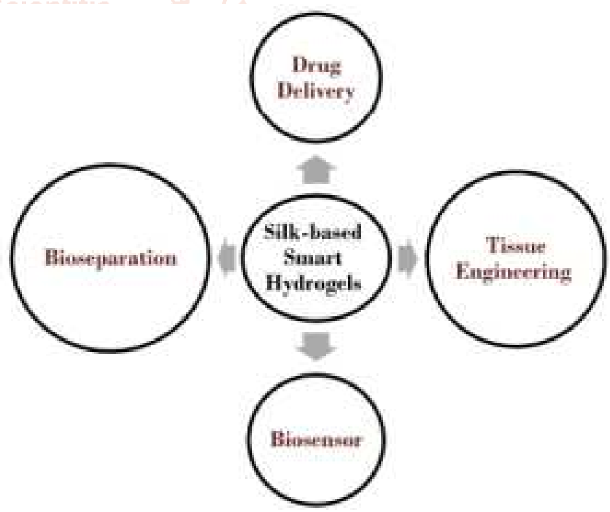


**Fig 2 Application areas of hydrogel in biomedicine**

**Self-organizing materials**

The research of self-organizing materials is structured as an international partnership. This encompasses a wide range of trends, including those that purge themselves or mend themselves. In the field of renewable energy, self-cleaning technology is becoming more and more popular. One method involves covering solar cells with hydrophobic materials, such titanium dioxide, to prevent dirt and moisture from sticking to the module. Some materials can mend themselves, including elastomers,

polymers, and ceramics. Both internal and external factors contribute to its operation. The former occurs inside the substance in response to an outside force. As an example, a 2008 research by Song et al. outlined the multistage response that is extrinsic healing. It begins with the delivery of material to the wounded location and continues with receiving healing from an external system. Eventually, the region is healed. Chemical processes, on the other hand, are responsible for intrinsic healing. When subjected to extrinsic processes, these polymer matrix healing agents take the form of (microscale) vascular networks or capsules. Upon damage, these chemical messengers would go to the site of the wound or break and fix it (Urdl et al., 2017).

**Quantum-tunneling composites**

Designed with the conductor components isolated from one another and, by extension, from the current flowing through them, quantum tunneling composites consist of a metal conductor and a polymer insulator. Applying pressure causes the conductor's parts to move closer together, which improves the current's ability to flow through them. Devices that detect pressure use this kind of smart material.

**Gels: hydragels and aerogels**

Some liquids have their weight retained by these compounds. Figure 2 shows their possible use in the oil sector, energy storage, and drug delivery.

One usage of smart hydrogels in biosensing systems is the identification of certain biomolecules, such as Le. the building blocks of proteins, DNA, carbohydrates, and enzymes etc. Using the fast-crosslinking gelatin methacrylamide and the pH-responsive hydroxyethyl acrylate carboxymethyl cellulose as examples, a composite hydrogel was created by crosslinking the two molecules. See Figure for reference. Image 3(a) and 3(b) show the pll-sensitive composite. Based on the pH-produced swelling ratios (Fig. 3(c) and (d)), the hydrogels expanded less when the glucose concentration was high (pH reaches low value) compared to when the glucose concentration was low (pH reaches high value).

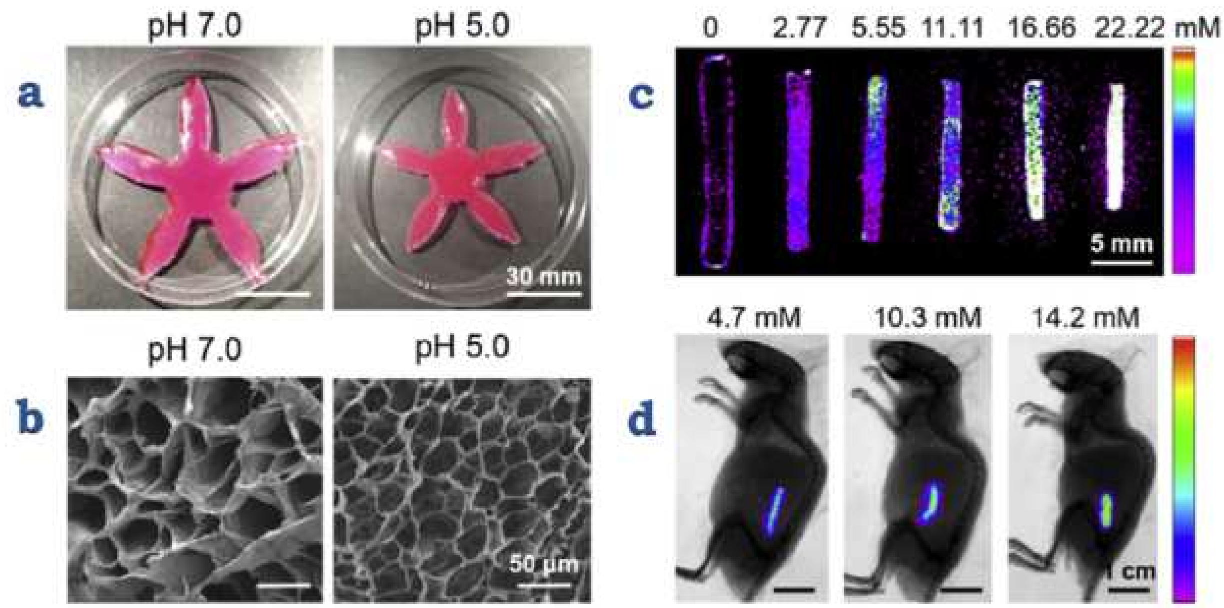


**Fig. 3 Smart hydrogels for glucose detection: Swelling of hydrogels at varied pH values (a), SEM images of hydrogels at varied pH (b), Smart hydrogels incorporated in different concentrations of glucose solutions (c), Fluorescence images of hydrogels that implanted in mice at different levels of blood glucose (d). Reproduced from Wu, M., et al., 2019. A smart hydrogel system for visual detection of glucose. Biosensors and Bioelectronics 142. 111547.**

For lectin detection, photonic crystals were incorporated into the carbohydrate hydrogel. According to Cai et al. (2017), the diffraction wavelength of hydrogels will be drastically changed since their volumes would decrease due to this interaction.

The unaided eye can see that the volume of the hydrogels changed when ennuymes were discovered. Another advantage of this detection method over more conventional analytical approaches is that it does not need costly or expert-level equipment or staff (Guo et al., 2020).

**Passive Smart Materials (PSMs)**

Materials with the intrinsic capability to transduce energy are known as passive smart materials (PSMs). Fiber optics, ferroelectric and piezoelectric materials, and others fall under this category.

**Piezoelectric materials**

When exposed to extreme mechanical stress, piezoelectric materials such as quartz, lithium niobate, and Pb(Zx 1,...,Tl n)O 3 generate an electrical current. On the other hand, as current flows through them, the material structure deforms. Most people are familiar with these SMs from their use in accelerometers, actuators, pressure transducers, medical devices, sporting goods, strain, pressure, and distributed vibration sensors, among many other potential uses. One of its advantages is that they have lightning-fast reactions. Draw a diagram. The most common piezoelectric composites used in different fields are shown in Figure 4.

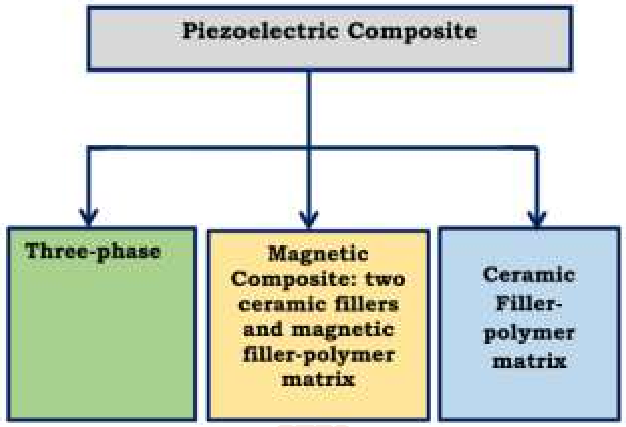


**Fig. 4 Classification of piezoelectric composites. Reproduced from Ribeiro, C., et al., 2018a. Piezoelectric Polymers and Polymer Composites for Sensors and Actuators. Elsevier.**

Due to its cheap cost, high sensitivity, and rigidity, lead zirconate titanate oxide (PZI) outperforms other super materials (SMs). Because of these features, it may double as a sensor and an actuator. The production process involves heating a specific mixture of lead, titanium dioxide, and zirconate to temperatures ranging from 800 to 1000°C. Sintering the powder to the desired size follows the use of a binder. Common practice calls for mounting PZT-based sensors on the necessary infrastructure surface and connecting them to an impedance analyzer for current generation. Using PZI transducers, the infrastructure is monitored. According to Maurya et al. (2020), their detection ranges for RC structures are 0.4 meters and 4 meters for metal beams. A model for the thermomechanical loading impact was developed by Hassan Elahi et al. (2018) after they investigated the impacts of different electrical and thermal loads on barium titante and used numerical methods to analyze the results.

In 2019, Fingiang Li et al. created an empirical formula that describes the motion of a piezoelectric material that is employed as an actuator. To arrive at the formula, the Rayleigh-Ritz and Hamiton methods were used. If the external control volume is carefully monitored and the material structure is adjusted, promising results may be achieved (Li et al., 2019).

Piezoelectric energy harvesting is a more recent method that uses piezoelectric material to store mechanical energy from the surface of an aircraft and then turns it into electrical energy when a force is applied. For harvesters, piezoelectric materials are highly recommended due to their high energy storage capacity per volume. Intelligent aircraft components and power sources for micro and UAVs were their dual roles. In addition, they are able to accurately inject the fuel, as stated by Sharma and Srinivas (2020).

Films, ceramics, and crystals were used in micro systems as an effective substitute for the traditional actuator and sensor due to their diminutive size (Zhang et al. 2016). According to Matvernko et al. (2012), the PZT dynamic characteristic has been optimized and simulated using external circuits. Helicopter rotor blades and cars both make use of ceramic fibers with piezoelectric filaments, but they have different shapes. This helps to reduce vibration and noise.

**Ferroelectric materials**

When heated, electrical polarization is seen in some pyroelectric materials, such as gallium nitride. This current was reversible in ferroelectric materials when exposed to a strong electric field, as the one generated by harium titanate in capacitors. Electronic devices such as ferroelectrical random access memory (RAM) will use these materials in the future. Compared to regular RAM, it is less expensive and has less stability.

Solution casting and quenching of 2D platelets were used to create the BaTiO/polyvinylidene fluoride (BT/PVDF) composite. Both the nanocomposite's energy storage capacity and its dielectric characteristics were

found to be significantly enhanced. With a discharge energy density of 9.7 1 cm at 450MV * m ^ - 1, the composite film, which contains 1 weight percent BT, outperforms presently available biaxially oriented polypropylenes by a factor of almost five. Reference: Wen et al. (2019).

**Electroactive polymers**

The invention of electroactive polymers was made by Willhelm Röntgen in 1880. When the rubber band was shocked electrically, he transferred a few more centimeters of length. A material's form, length, or volume may be changed by applying an electrical current to an electroactive polymer. Their ability to endure high loads and significant deformation makes them preferable than piezoelectric ceramic actuators. These are essential for creating animatronics and artificial muscles that are more lifelike in the future. Both wet-type Ionic and dry-type Dielectric brands are available. Actuation occurs in a dielectric when a passive polymer is sandwiched between two electrodes and exposed to a voltage. Conversely, an ionic function occurs when an electric current changes the locations of the polymer's ions.

Electroactive polymers include dielectric elastomers (DEs). Energy harvesters and robots may make use of them due to their distortion caused by an external electrical field (Mansor and Akop, 2020). While submerged, an energy-collecting device developed by Leng et al. causes the stacked DEs actuators to compress many times. To generate energy from mechanical motion, the device is subjected to waves that consistently travel up and down (Leng et al., 2011). According to Prahlad (2005), it was found that the polymer engine generator's cylinder wall also used DE, and that this polymer enhanced fuel leakage and heat loss.

**Electroluminescent materials**

Electroluminescent materials are those that release light when exposed to an electric current. These materials continue to find substantial use in modern electronics. They are just as effective as gallium arsenide for lowering LCD power consumption. Additional investigation into these materials will center on the alteration of light colors with the use of doping. A vivid blue light is produced by doping zinc sulfide with silver, a green light by doping the same material with copper, and the process continues thereafter in the same manner.

**Chromic materials**

A family of smart materials known as chromatic materials may undergo color changes in response to changes in temperature, magnetic field, light irradiation, electrical state, and mechanical pressure. This class includes thermochromic, electrochromic, and piezochromic materials. Substances like silver chloride find use in a wide variety of applications; for example, color-changing eyewear.

**Optical fiber**

Nanoscale optical fibers are thin, cylindrical devices that may respond to environmental stimuli by emitting optoelectronic signals. Their composition includes polymers, zeones, topas, and silica. Detectors, light modulators, and sensors—composed mostly of inner and outer fibers—are their primary uses. Optical fibers have the advantages of being strong, lightweight, and heat-proof, as stated by Jin et al. (2002) and Bhandwaj et al. (2020).

**Recent in Smart Technologies**

The backbone of several technological systems are intelligent materials. They will be quickly covered in the section that follows:

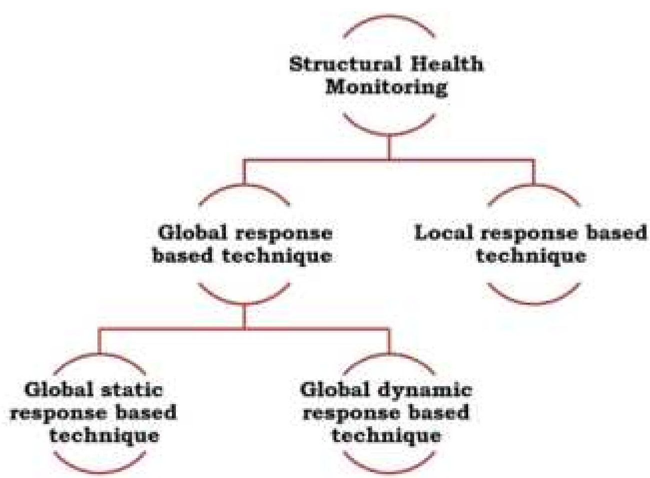


**Fig. 5 Classification of structural health monitoring.**

### Structural Health Monitoring

Structural engineers employ the structural health monitoring (SHM) method to identify and describe deterioration. Fig. explains the big picture of this method and how it works. number five (Maurya and others, 2).

### Morphing Technology

Morphing is the process of altering the form of a building to meet a certain need. Materials' capacity to exhibit varying internal anisotropic characteristics determines the efficacy of this method. The fundamental challenge with this technique is bringing together the material's two opposing properties, high stiffness and reversible deformation, for the same material (Sharma and Srinivas, 2020).

The use of blended bi-stable laminates was proposed by Ajit S. Panesar et al. Designing an aircraft wing is a good illustration of this kind of application since the structure is exposed to extreme loads that cause bending strains and fatigue failure. The wings need to be strong so they can endure this kind of stress. However, the critical load limitations are too high for these loads (Panesar and Weaver, 2012).

Taking into consideration properties associated with this temperature shift, a model was created to forecast the morphologies of multistable laminated plates subjected to various thermal stresses. Through the use of Ritz minimization methods, solutions were attained with constant curvature form functions. Throughout a wide temperature range, the model faithfully depicted the effects of temperature on the associated attributes (Eckstein et al., 2013).

### Additive Manufacturing

Additive manufacturing is based on the manufacture of complex structures and objects via the use of highly precise design and efficiently operated computers. The rapidity, narrow geometric limit, low production costs, and exceptional accuracy of this process—also called 3D printing—stand out. It reduces the overall mass and number of components as well. Due to the traditional method's cheap total cost and good dependability, this technique is still not suitable for mass production, despite its superiority for low-volume items (Falahati et al., 2020). Draw a diagram. Number 6 contains the primary ingredients used as additions in this process. 4D printing, which allows printed materials to undergo controlled and predictable changes, will allow SMs to be used more often in 3D design and manufacturing. The electronics, aviation, transportation, and healthcare sectors are among those that will feel the effects of this shift. Technologies from SMs, the manufacturing method, and equipment are all used in the fabrication process. Palmero and Bollero list seven different forms of spray polymerization: material jetting, vat photo-polymerization, powder bed fusion, sheet lamination, and directed energy deposition (2020).

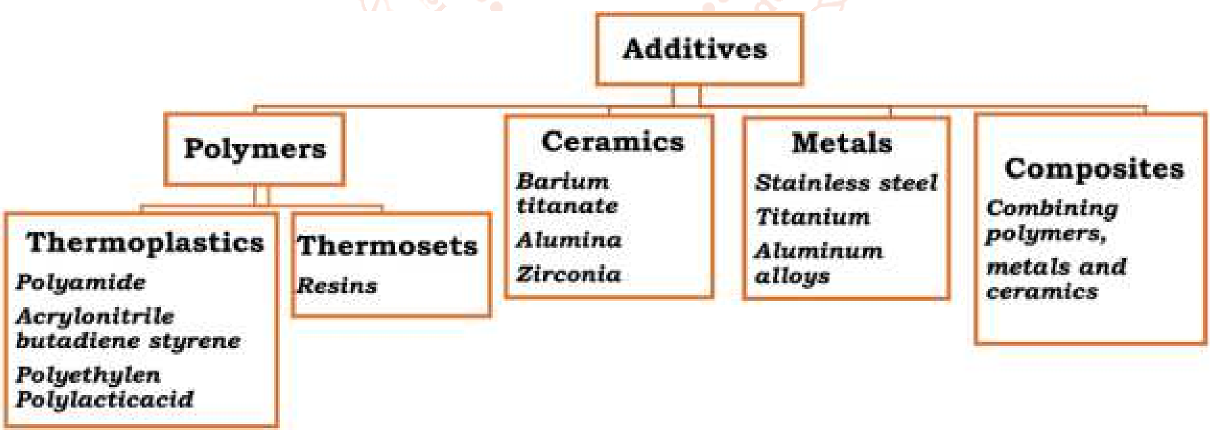


**Fig. 6 classification of additive manufacturing materials.**

### Smart composites used in 3D and 4D printing

1. In order to create magnetic composites, non-magnetic matrices are combined with magnetic characteristics. The final printed object is influenced by many factors, including the design, precursors, composite synthesis, and 3D printing. Printing three-dimensional objects with magnetic response was accomplished by Zhu et al. using a direct writing approach. They combined poly-dimethyl siloxane with nanoparticles of magnetic iron to create 4D printing ink. Zhu et al. (2018) reported the development of a three-dimensional terahertz photonic crystal that exhibited rapid reaction times and could be remotely adjusted. Kim et al. created materials with magnetic field-responsive rapid and accurate deformation by incorporating boron, iron, and neodymium particles into their ink. The biomedical device, soft robotics, and flexible electronics industries might benefit from multi-domain shape-shifting SMs (Kim et al., 2018).

2. Composites that are thermally adjusted have an enhanced heat conductivity due to changes made to the orientation of the fibers.
3. Composites used in reinforced architectures: by including certain fibers into the composite, the mechanical qualities of certain building components may be improved.
4. Electrically conductive composite materials are used in electronics and sensing equipment.

One method for creating flexible electrical devices, such temperature sensors, is to inkjet print conductive ink containing carbon nanotubes or silver nanoparticles onto printed shape memory polymer structures.

The fabrication of multi-shape memory items was accomplished by using materials with varying transition temperatures. For instance, according to Wu et al. (2016), an elastomeric matrix that includes SMP fibers was used to generate things with many form alterations that were controlled thermomechanically. Making adjustments to the 3D printing settings, thermomechanical loading profile, and precursor composite material qualities allows for control over the spectrum of form changes in the generated things (Falahati et al., 2020). Draw a diagram. 7 lists all the many kinds of printing.

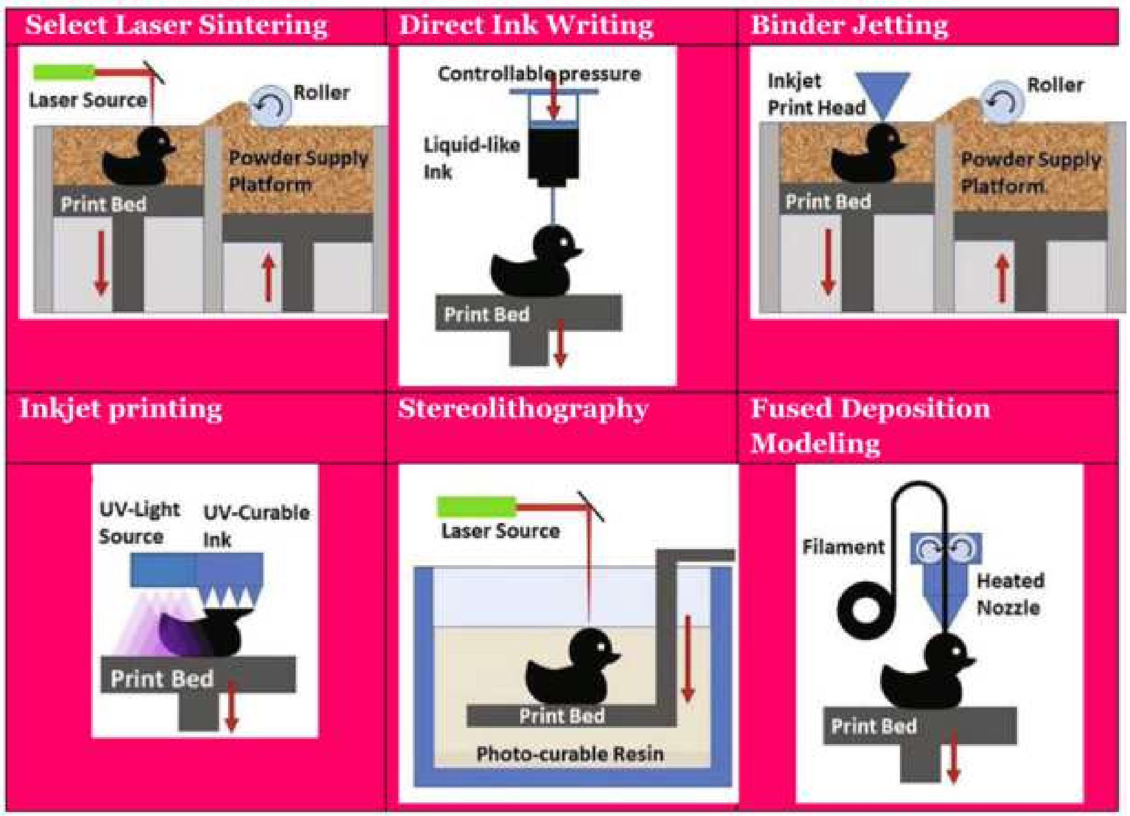


**Fig. 7 The 3D printing techniques. Reproduced from Falahati, M., et al., 2020. Smart polymers and nanocomposites for 3D and 4D printing. In Materials Today 40, 215-245.**

An SM is the fundamental component of a 4D printing process. These are the only components that make up this approach. The hallmarks of the four-dimensional printing method are the material's qualities and the incorporation of several attributes. The modeling approach is the other crucial part. Nevertheless, there are some constraints on the subject matter, methodology, and layout within this area of research. Draw a diagram. The eight primary areas where this method is lacking in study are highlighted by Falahati et al. (2020).

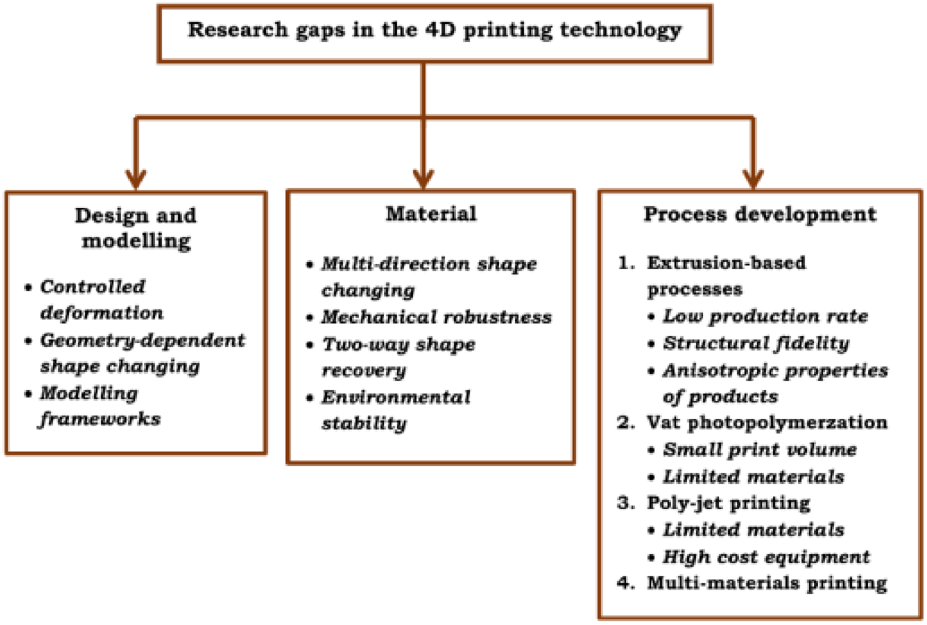


**Fig. 8 The main research gaps in 4D printing research and technology.**

**The Next Generation of SMS in Different Sectors**

The following sectors make use of the next generation of smart materials because of their distinctive properties:

**Energy Application**

Smart materials for energy production and harvesting, such as polymer-based composites, are becoming more popular. Because of their low density, which improves compressive loading during energy absorption, promotes electrical conductivity, and strengthens composites, nanotubes were proposed for use in polymer-based composites. One example of such a composite is a combination of single and double carbon nanotubes with polyphenylenevinylene; this material has great heat conductivity and almost little photoluminescence loss (Rao and Cheetham, 2001). Composites with strong electrical qualities, little environmental impact, and reasonable prices are relatively uncommon; one such example is polyaniline nanocomposite. They might be used in conjunction with electrochromic devices, capacitors, and rechargeable batteries, say Thomas and Zaikov (2008).

**Biosensing**

It is necessary to track certain biomolecules in order to identify specific diseases. Some diseases, such as diabetes, obesity, and cancer, may be diagnosed by measuring blood glucose levels; others, such genetic and neurological disorders, cancer, and diabetes, can be detected by analyzing proteins. In addition, nucleic acids may be used to identify cancer and genetic disorders.

Nanorods, quantum dots (QDs), gold nanoparticles, and multiwalled carbon nanotubes are only a few examples of the nanomaterials whose properties have made nanotechnology a boon to biosensing. Fig. 9 shows that modified gold nanoparticles were used to detect glucose. When glucose was present, the particles did not aggregate and the solution color remained red. However, when glucose was absent, the particles did aggregate and the solution color became violet.

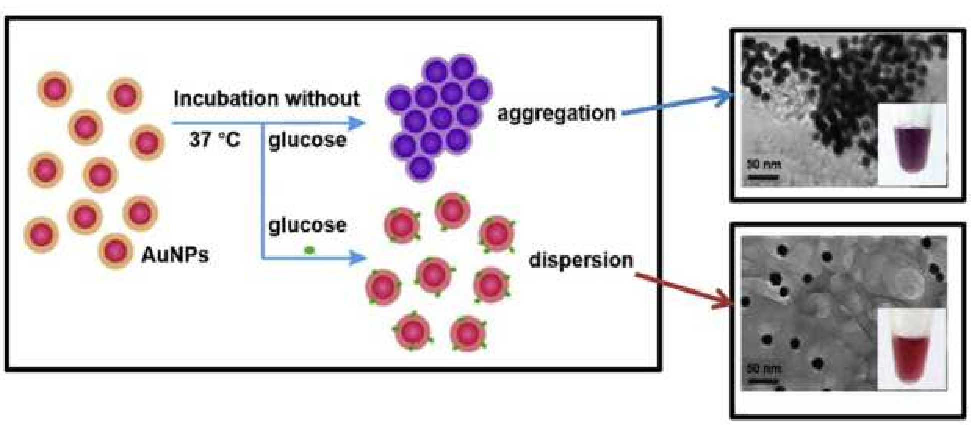


**Fig. 9 Gold nanoparticles for colorimetric sensing of glucose.**

For the goal of screening multiplex tumor millNA, silica colloidal crystal barcodes (SCCBs) augmented with quantum dots (QDs) and coupled with molybdenum disulfide (MoS) were created. Quantum dots regain their fluorescence after being released from MoS sheets when the probe forms a double strand with the target miRNA. With the nucleic acid concentration being directly proportional to the amount of QDs released. It would then be possible to measure the miRNAs. As an alternative to the conventional PCR method, Bian et al. (2019) report the discovery of three distinct types of highly sensitive tumor miRNAs. And since they have different optical properties, enzymes may be identified using gold nanoparticles and quantum dots (Howes et al., 2014).

**Building and Construction**

Iran was the site of an extensive study of the use of several SMs to building facades. When used to building facades, thermochromic, photovoltaic, and photostrictive materials provide many benefits, including reduced energy consumption, increased earthquake resistance, and improved safety (Lalali and Valipour, 2020).

According to Azens and Granqvist (2003), electrochromic SMs used in windows might result in a 170 kWh reduction in energy consumption. By decreasing the solar heat gain coefficient in glazing during summer, eliminating typical shading devices and artificial lighting, and reducing glare, the use of SMs in windows saves cooling loads while still providing an unobstructed view of the surroundings. SMs use high transmittance states to their advantage during winter, allowing them to optimize passive solar heat uptake (Piccolo, 2010).

Tällberg et al. (2019) found that electrochromic materials used the least amount of energy compared to commercially available thermochromic and photochromic materials. Operating temperature, irradiance impinging the outside surface, and Le illuminance level on a work plane were the three control techniques that were evaluated in the research.

**Aviation Industry**

SMs continue to contribute to the advancement of aircraft technology thanks to their extensive background in the aviation sector. Due to their exceptional controllability and compactness, shape memory based and piezoelectric materials are the ideal choices for manufacturing wings. According to Shahir et al. (2018), SMs should allow the structure to temporarily or permanently bend while keeping structural integrity in all suspected and unexpected scenarios. Still, they're having trouble losing weight. Draw a diagram. The suggested areas for the use of SMa in aircraft are shown in Figure 10.

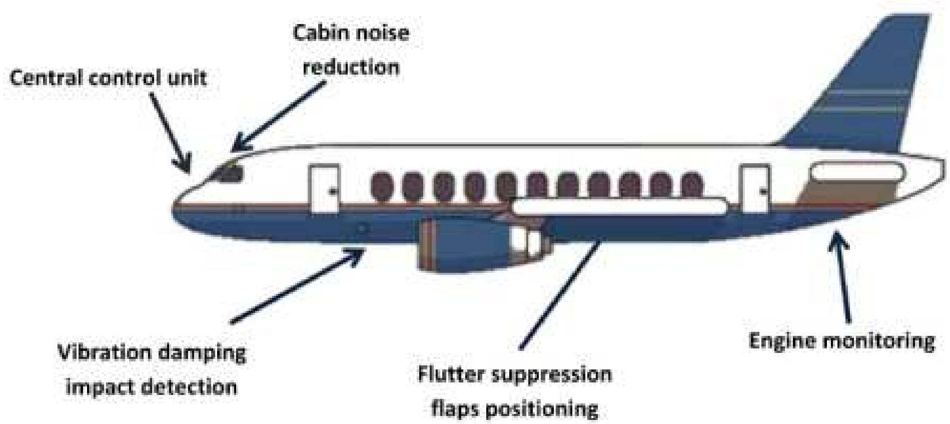


**Fig. 10 Possible locations of SMS in an aircraft. Reproduced from Akhras, G., 2000. Smart materials and smart systems for the future. Canadian Military Journal 1 (3), 25-31.**

**Electronic Applications**

Printed bio-electronic devices of the future will take design cues from smart biomaterials now employed in optical and electrical devices. By incorporating gold nanoparticles into the fibroin biopolymer, resistive memory devices were created (Gourla et al, 2013). Trioris et al. used a microfluidic device to link functionalized silk to a polydimethyl siloxane elastomer. It controls the spatial and temporal supply of solutions to the system, providing an optical response to the device. The modified silk is defined by its stability and broad spectrum response range, according to Tsioris et al. (2010). A graphene/silk pressure sensor with a sensitivity of 0.4 kPa and a maximum pressure detection range of 140 kPa was created by Liu et al. (2017).

**Medical Applications**

Because of the important roles that smart materials play in improving therapeutic efficacy and selectivity, they are capturing the attention of medical researchers. Their primary functions are outlined below:

- Many recently developed smart materials have potent characteristics that make them ideal drug carriers. This opens up exciting new possibilities for medication administration. The medication delivery system is guided by the magnetic field that Tian et al. build. Their strategy included loading doxorubicin-loaded magnetic silk fiber nanoparticles with cancer cells. Through alterations to the magnetic nanoparticles, they improved the production process (Tian et al., 2014).
- Dressing for wound treatment and drug delivery control: a hydrogel dressing comprising medication and plf-responsive alginate scaffold arrays was applied. Mirani et al. (2017) states that this hydrogel dressing can measure the depth of wound infection and respond to changes in swelling and pit size by releasing regulated antibiotics.
- The year 2016 saw the development of a new kind of silk suture. Their tensile strength increased to 626 ± 23.3 MPa and knot strength to 388.6 ± 16.8 MPa, respectively, when SMs were added, along with their antibacterial properties. In a study conducted by Francis et al. (2016), it was shown that SMs have the potential to be beneficial in the treatment of cardiac conditions, aneurysmal embolization, and arteriovenous occlusion.
- The field of dentistry has been profoundly affected by the SAts. The frequency of conservative cavity preparation was increased, and the tooth's structure was strengthened. Two of these materials, dentin and enamel, may imitate the structure of real teeth. Some examples of dental SMs include orthodontic shape memory alloys, smart sutures, impression materials, and burs. Moreover, materials for restoration, include smart ceramics/composites, resin-modified glass ionomer, etc. (Gupta, 2018).
- These SMs have revolutionized tissue engineering. Researchers and cancer patients have discovered that real-time controlled hydrogels may reduce tumor development. The hydrogels of responsive silk fibroin were produced in a physiological setting using the crosslinking process of horseradish peroxidase (Ribeiro et al., 2018b).

**Environmental Management**

Sayed et al. (2020) and Shafock et al. (2020) list many industries, agricultural practices, and environmental spheres that have made use of smart nanoparticles. In addition, the water and wastewater treatment industries have shown encouraging results using certain intelligent nanoparticles. EL. A number of pollutants can be attached to them at once, including carbon nanotubes for managing biochemical and chemical oxygen demand, heavy metals (E-Naggar et al., 2015), clays (Egirani et al., 2020a, 2020b), and many more (Rabiei et al., 2017).

**The Opportunities and Challenges**

Our current resources are limited, thus it is our responsibility to utilize them wisely and sustainably. According to UNESCO, there are seventeen objectives for sustainable development (UNESCO, 2020).

Achieving these goals is highly dependent on creating and using the next generation of SMs. For instance, one way to reduce energy consumption and achieve the twelfth purpose (sustainable communities and cities) is to include thermochromic, electrochromic, and photochromic smart materials into buildings.

Use of smart materials and technologies in biological applications (health and wellbeing) is another example that bolsters the third goal. A number of industries, including renewable energy and aviation, use smart materials and technology to help reach goals 7, 8, 9, and 17.

The lives and technologies of the future generation will be intertwined with social networking. They tend to be described as outgoing, clever, insightful, fashionable, and refined. The research of several engineering fields has shown a necessity for these materials. These fields include civil, energy, mechanical, biological, electronics, aerospace, military, and car engineering. All aspects of life will be enhanced by these changes in the end. For SMs to thrive and last, certain elements are essential:

1. The birth and spread of succeeding generations are mostly attributable to certain branches of science and technical advancements. This encompasses fields such as astronomy, biology, nanotechnology, mechanical engineering, civil engineering, and AI.
2. Promptly and precisely recognizing changes to content.
3. The following requirements must be met by any intelligent material used in the smart device or modem industry (Akhras, 2000):

- An SM's technical qualities include of chemistry, physics, mechanics, and electronics.
- dimensions, heat treatment, welding proficiency, workability, and contamination level are all components of technology.

- The availability, cost, and production process of raw materials are only a few of the many variables that impact monetary considerations.
- The following are some environmental problems: pollution, toxicity, reusability/recyclability, and sustainable development requirements.

There is a plethora of choice among the programs. Material architecture is the place to seek for ways to improve their performance. There is a lot of manual effort involved in tailoring materials to specific uses, reducing prices while limiting their negative effect on the environment, and improving production processes. We need to think about issues related to the safety of both humans and the earth.

Future SMs, on the other hand, won't be making lightning-fast progress. Theoretical and practical domains such as chemistry, physics, computer science, mechanics, electronics, engineering, and aeronautics are all part of the vastly interdisciplinary study of supermachines (SMs) and the technologies around them (Akhras, 2000).

**Conclusion**

This research paper aimed to highlight the features, composition, and structure of the next generation of smart materials—essential for achieving the improvements currently taking place in every field—and to examine the pros and cons of these materials' rapid growth. It covered the next generation of smart materials, including their varieties, unique characteristics, main application domains, and associated technology.

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